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Launch Pad Closeout Operations for the Mars Science Laboratory's Heat Rejection System

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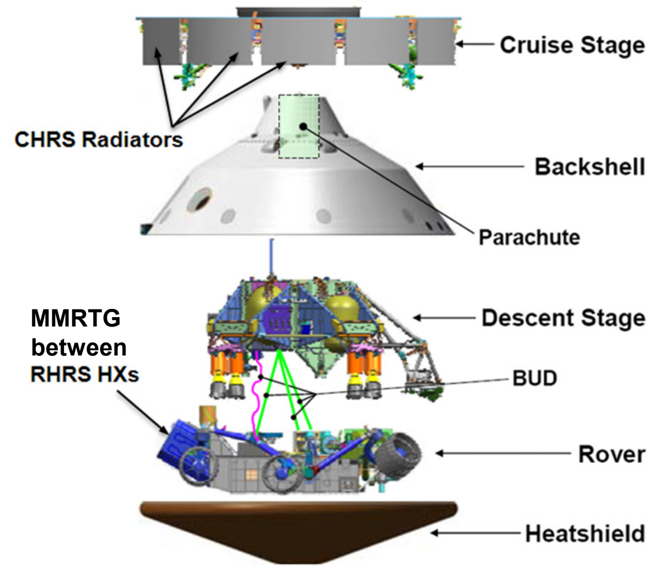
California Institute of Technology

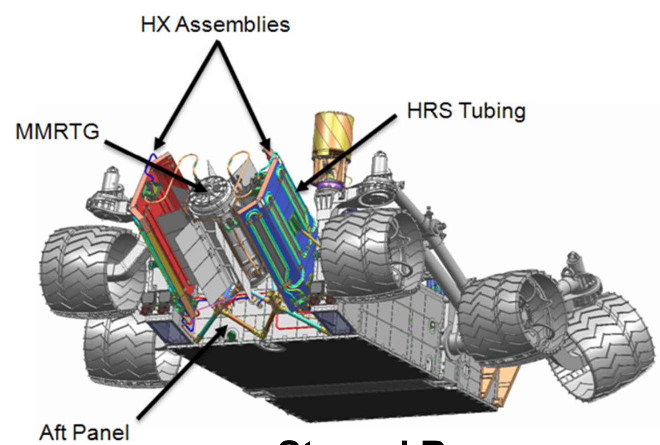
Agenda

- MSL Spacecraft & Rover Configuration
- Mechanically Pumped Fluid Loop Architecture
  - Primary Cruise HRS Loop (Flight Loop)
  - Primary Rover HRS Loop (Flight Loop)
  - Secondary Service Loop (MMRTG ground cooling during installation)
- Launch Pad Thermal Requirements
- Vertical Integration Facility (VIF) Description
  - MMRTG/CHRS Integration and Secondary Cooling on –X Side of S/C
  - CHRS Offload, Leak, and Fill Operations on +X Side of S/C
- Launch Pad Closeout Activity Flow
- Launch Pad Flight Temperature/Pressure Data
- Lessons Learned, Conclusions, & Acknowledgements

MSL S/C and Rover Configuration

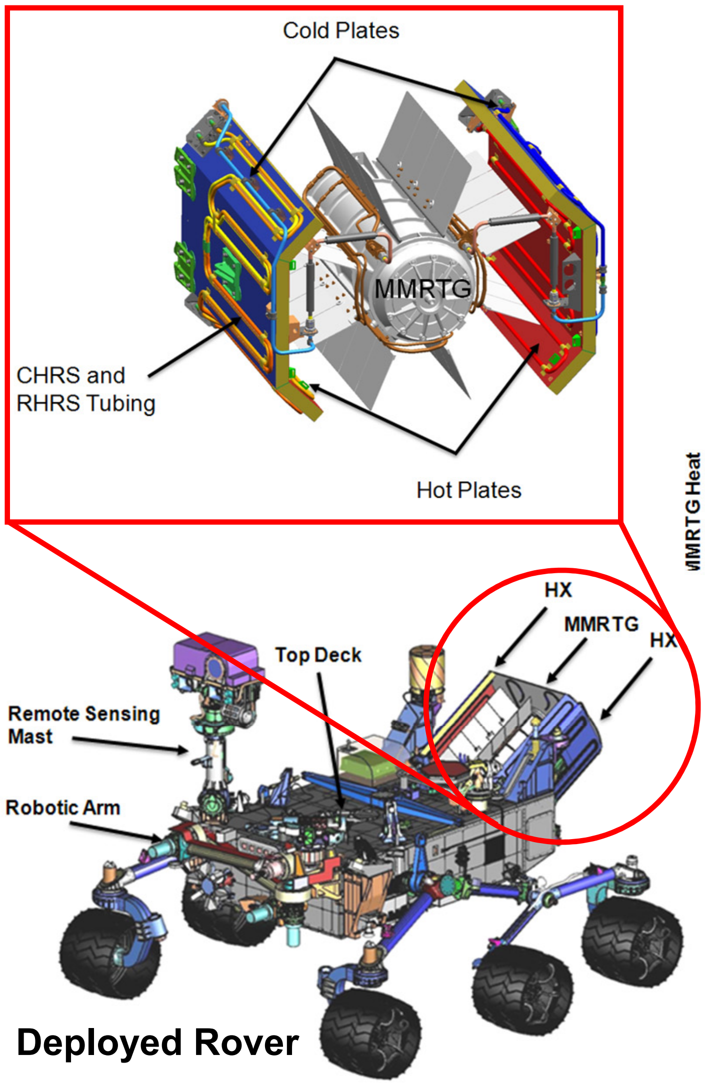
- Launched November 26, 2011, payload of 10 instruments
- Landed Phase Mission Duration: 1 Martian Year
- Required to fully operate on Mars between 30° North and 30° South latitudes *day or night*
- New power source required – Multi-Mission Radioisotope Thermoelectric Generator (MMRTG): 110 W electrical, 2000 W thermal dissipation
- Martian surface temperatures range from $-123^{\circ}C$ to $38^{\circ}C$ while Rover Electronics and Instruments need to be maintained at $-40^{\circ}C$ to $50^{\circ}C$
- Thermal Management provided by 2 Mechanically Pumped Fluid Loops (Freon): Cruise Loop (CHRS) & Rover Loop (RHRS)





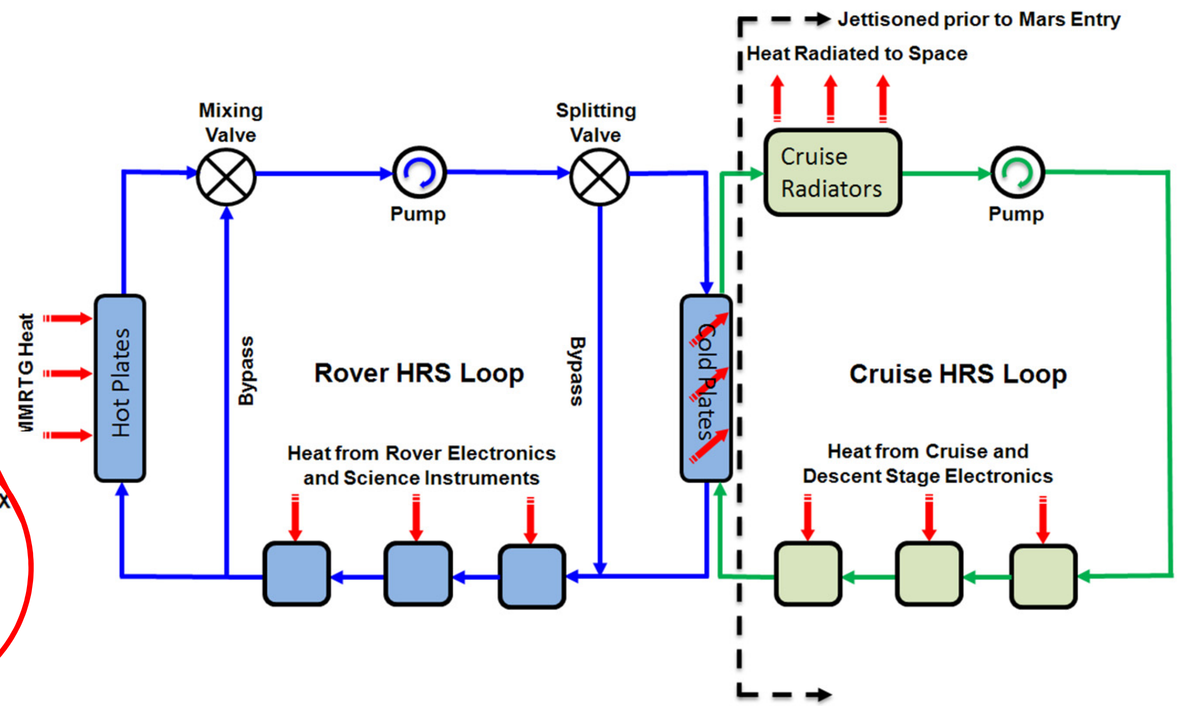
Stowed Rover

Mechanically Pumped Fluid Loop Architecture



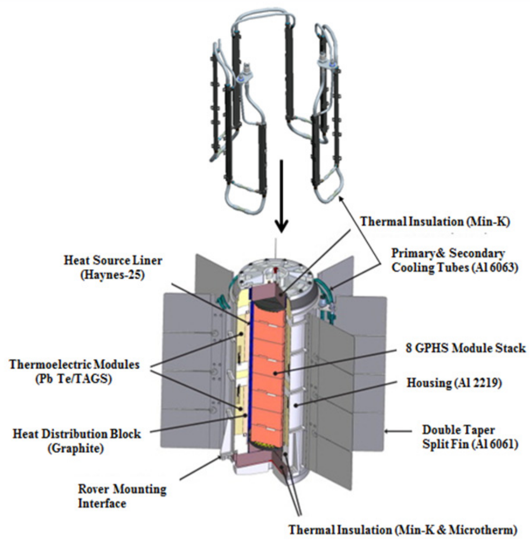
Deployed Rover

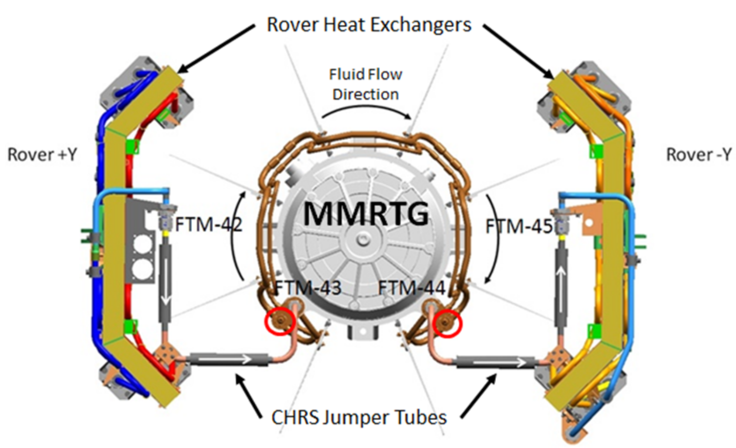
MSL Mechanical Pumped Fluid Loop Architecture



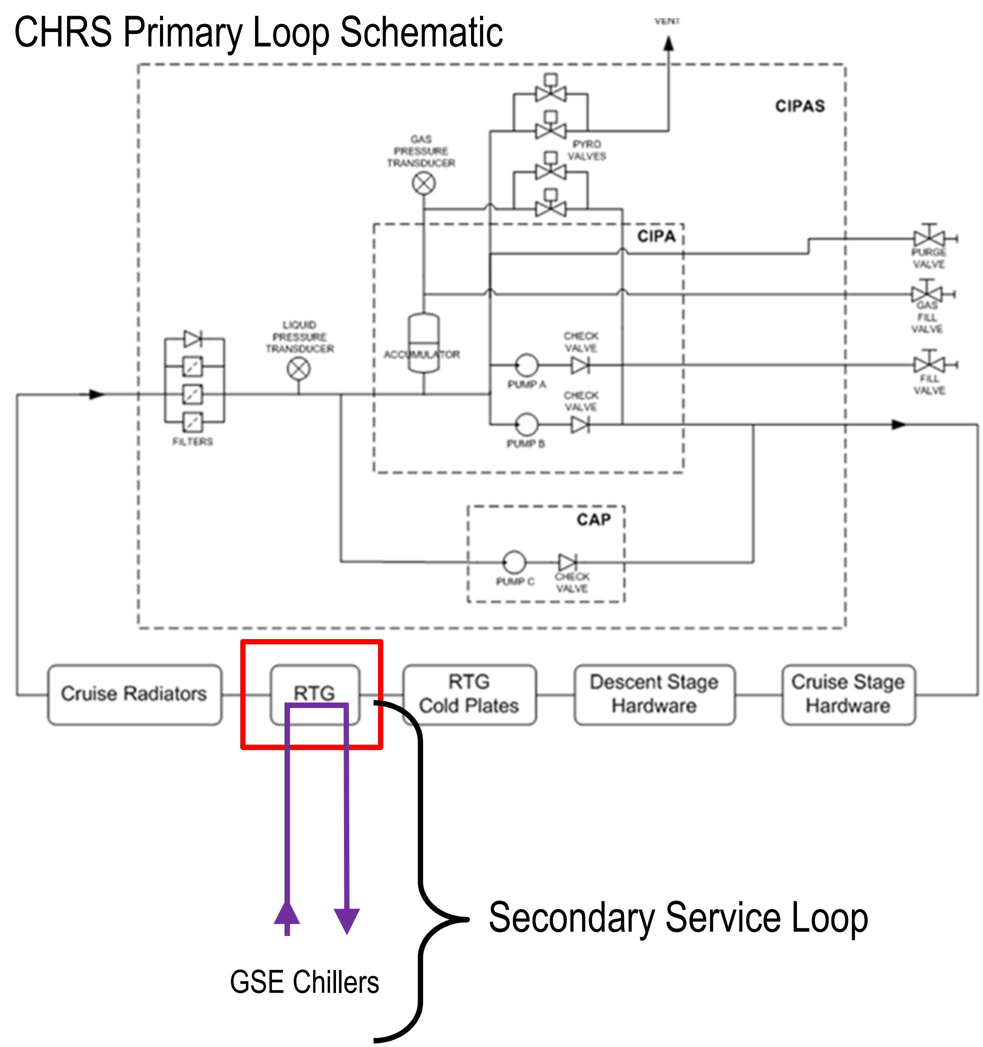
Simultaneously collect heat from MMRTG ***and*** reject waste heat to either the Cruise Loop or directly to Martian environment depending upon mission phase

Secondary Service Loop: MMRTG Cooling During Installation





MMRTG Installation as viewed from Rear of Upside Down Rover
Primary and Secondary Fluid Flow Direction is From Rover +Y to Rover -Y



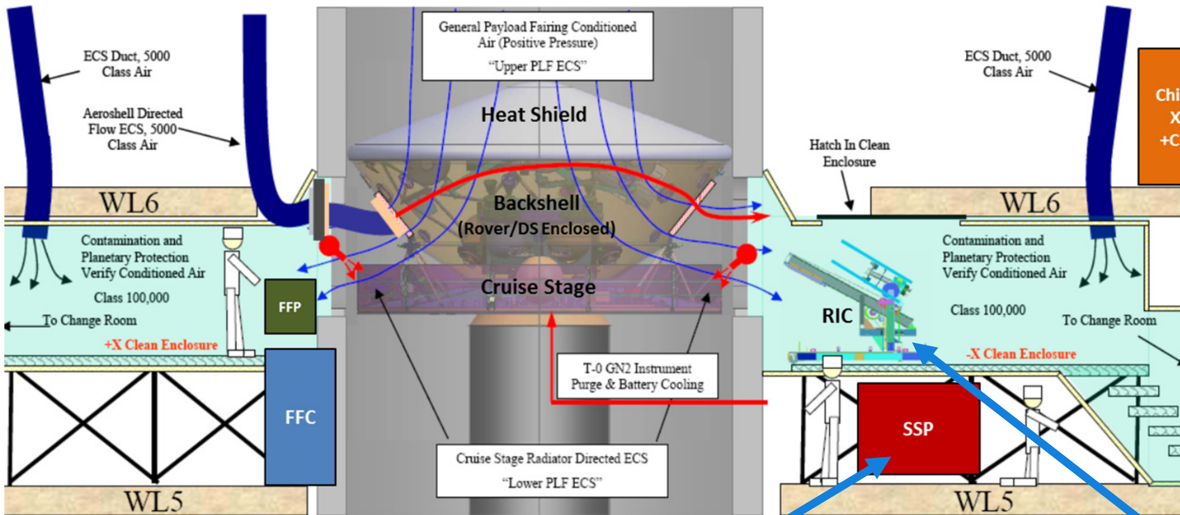
Launch Pad Thermal Requirements

- MMRTG fin root temperature within 100°C to 180°C
- MMRTG average fin root temperature not allowed to change by more than 18°C over a 10-minute period
- Critical propulsion system components and avionics < 50°C
- Total launch pad heat removal for the S/C = 2500 W (2000 W from MMRTG)
- JPL, ULA, and KSC performed detailed CFD analyses that showed if the MMRTG was not continuously cooled, the Descent Stage pressurant tanks would exceed their maximum AFT limit of 50°C in just 4 hours

Last Minute Launch Pad Constraint That Affected HRS

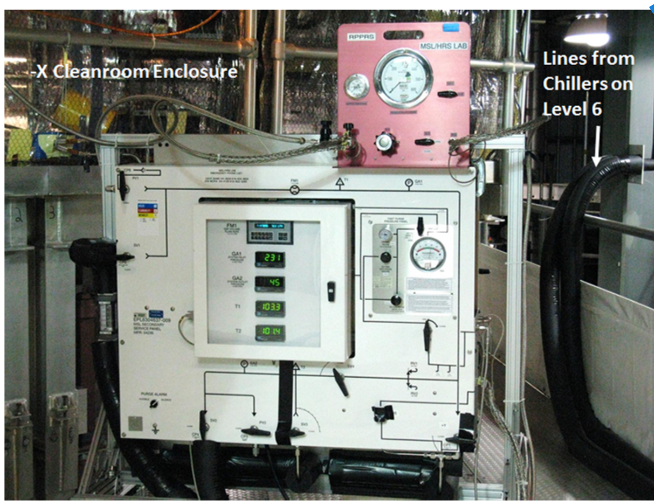
- Low probablity risk identified with potentially catastrophic consequences: CIPAS pumps could accidently be turned on by a flight software anomaly while the CHRS loop was not charged during the final flight software upload planned for the pad
- Running CIPAS pumps dry not recommended by manufacturer
  - Pump bearings designed to be hydrodynamically lubricated by CFC-11 during operation
- Leaving CIPAS electrical connector unmated prior to delivery to Vertical Integration Facility (VIF) deemed impractical due to limited launch pad access
- Therefore, project decided that CHRS would be charged with CFC-11 prior to delivery to VIF, and then offloaded while on the pad prior to MMRTG installation
- A preliminary CHRS fill would have to occur while the S/C was powered off in order to avoid running the pumps dry
- CHRS would be filled to final flight values after S/C was powered on and telemetry was available

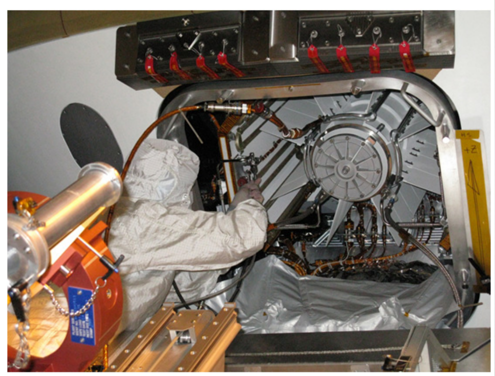
Vertical Integration Facility (VIF): MMRTG/CHRS Integration

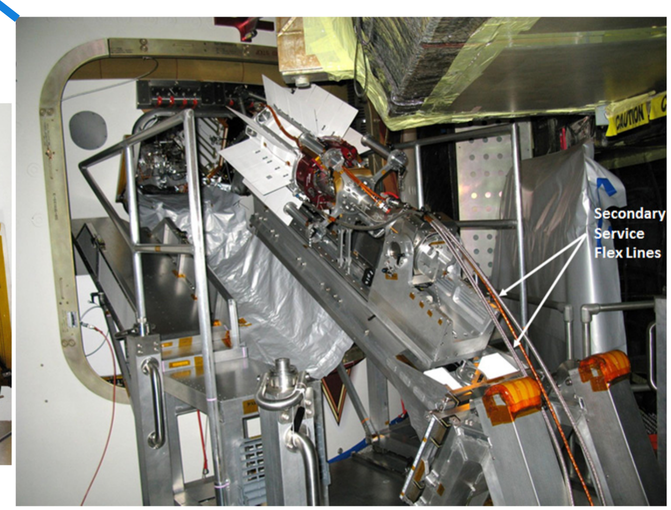


+X, CHRS Fill

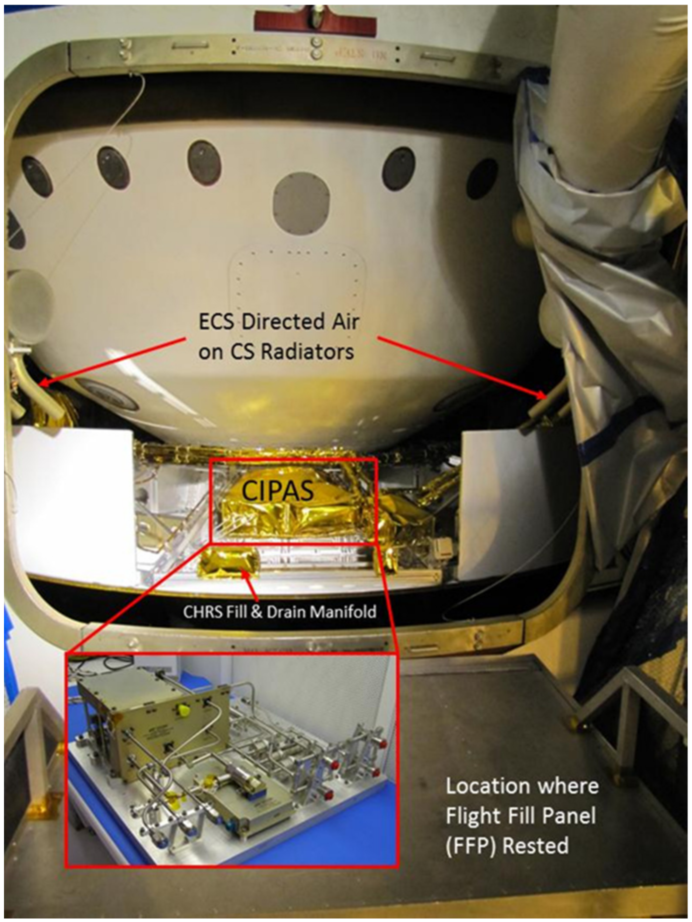
-X, MMRTG Integration
+ Secondary Cooling

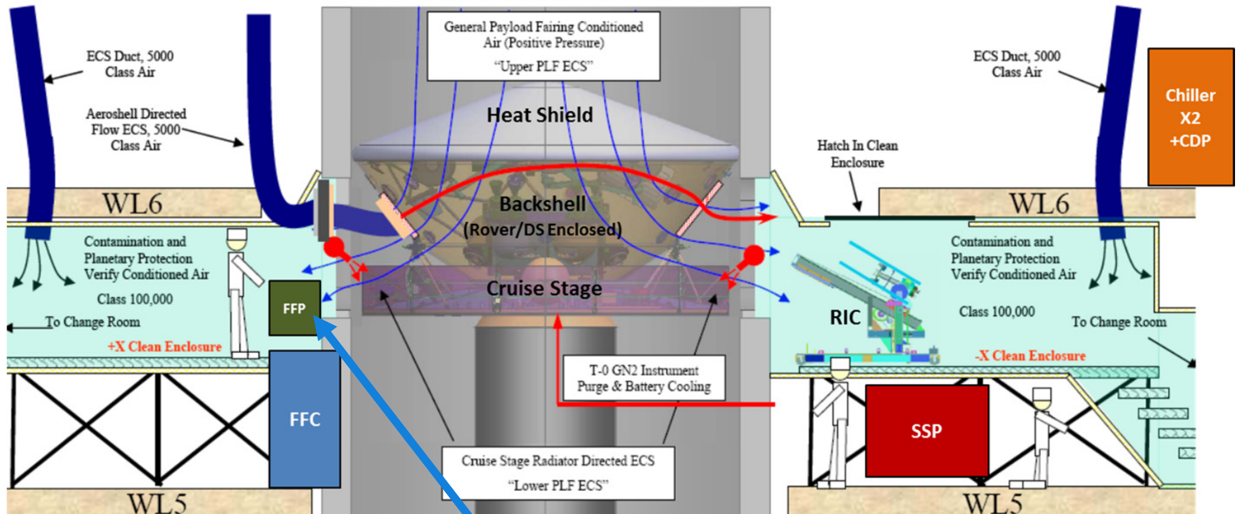






Vertical Integration Facility (VIF): CHRS Offload, Leak Check, Fill





+X, CHRS Fill

-X, MMRTG Integration
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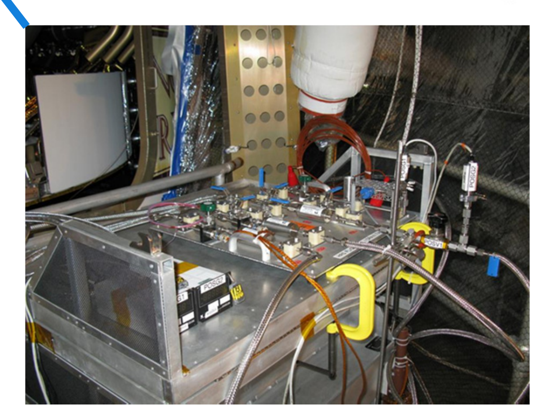
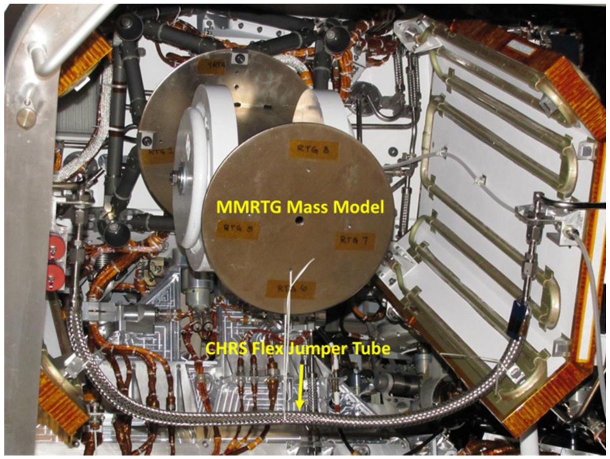
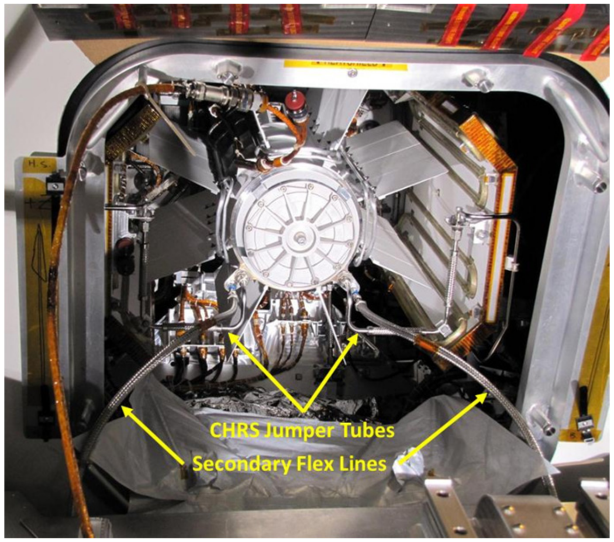


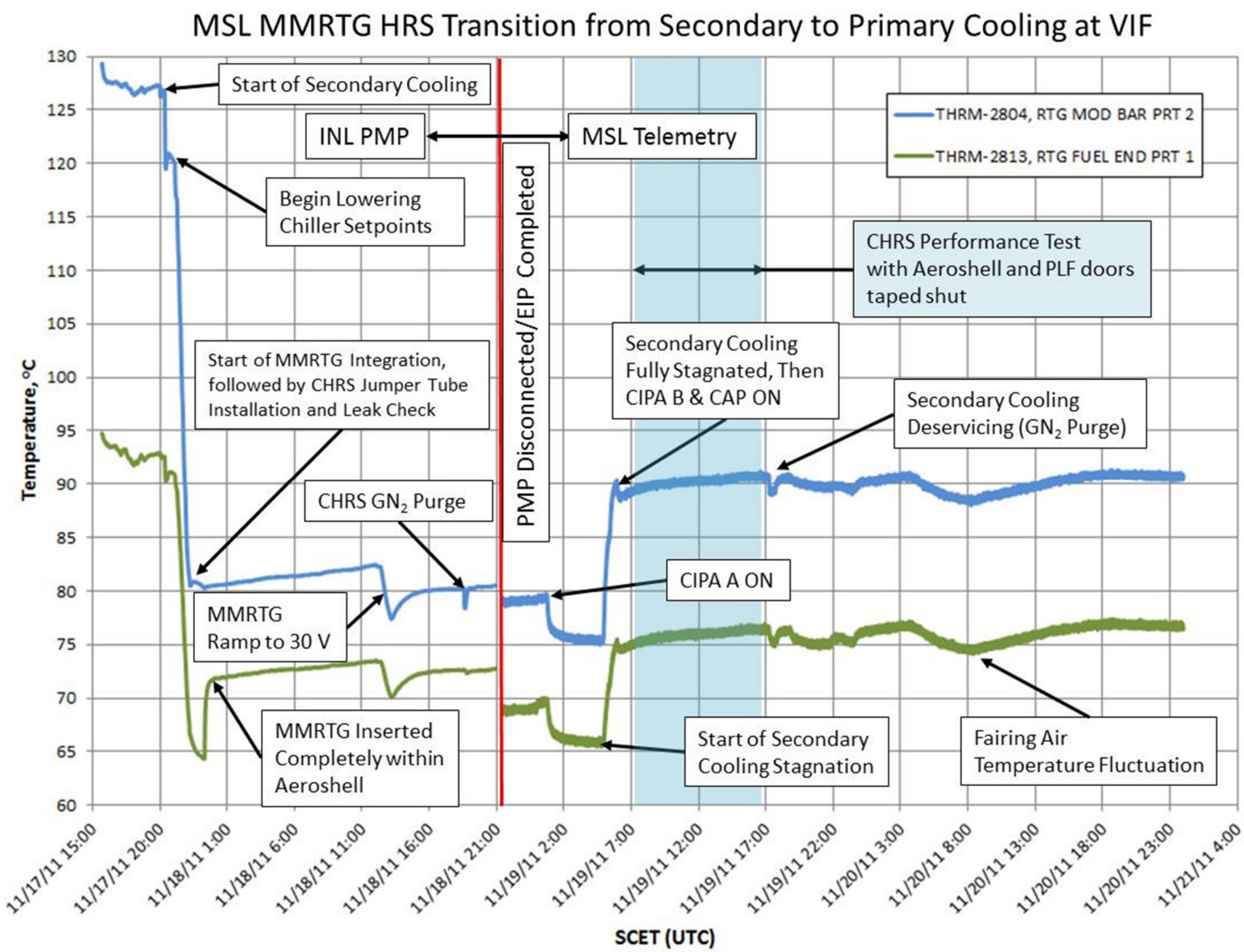
Launch Pad Activity Flow – Week of November 13, 2011

- CHRS offloaded, MMRTG mass model uninstalled
- MMRTG positioned on RIC
- INL PMP connected
- Secondary service lines connected, leak checked, and warmed Galden heat transfer fluid flowed into MMRTG
- Chiller setpoints were manually lowered to decrease MMRTG fin root temperature
- MMRTG installed onto Rover, CHRS jumper tubes installed
- CHRS leak checks, preliminary CHRS fill with S/C powered off
- S/C power on, INL PMP disconnected
- CHRS fill continued to final flight values based upon S/C telemetry
- CIPA-A ON, 5 hour period with primary and secondary cooling in parallel
- Secondary cooling stagnated
- CIPA-B & CAP ON, 10 hour performance test
- + X Closeouts, secondary cooling deserviced, - X closeouts

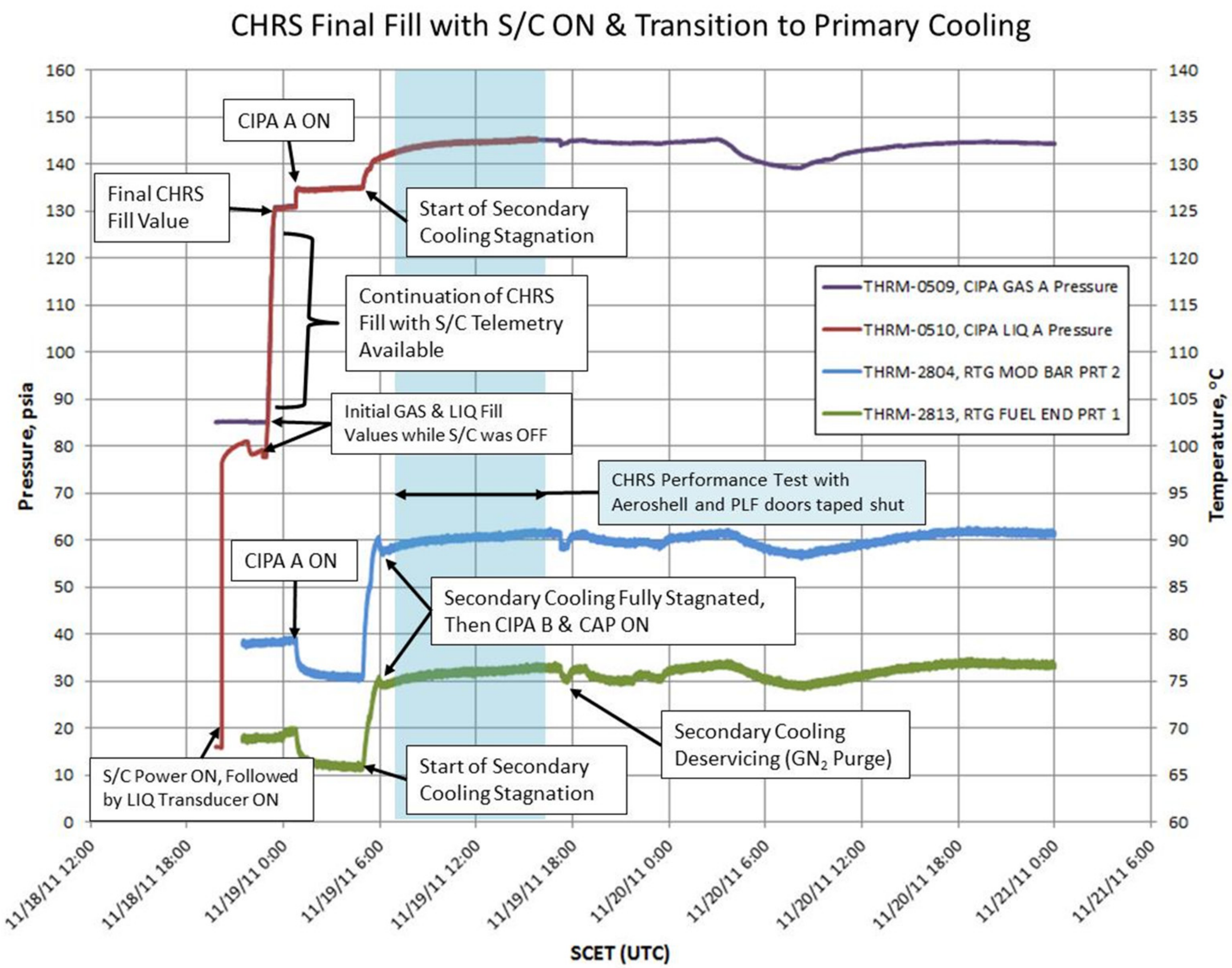




Launch Pad Flight Temperature Data



Launch Pad Flight Temperature/Pressure Data



Lessons Learned

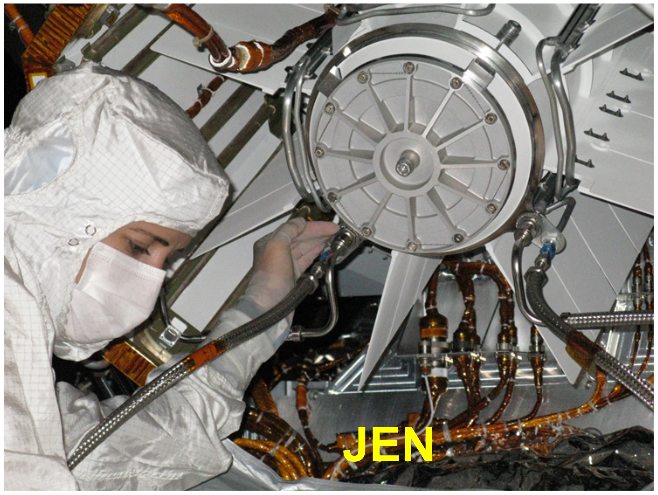
- A-N fittings used for the secondary cooling tubing assembly should not have been fabricated from aluminum
- An inspection of the MMRTG fluid fittings should have occurred prior to fueling the unit with plutonium
- A prototype was essential to the successful development of the chillers used to pre-cool the MMRTG; several serious problems identified early including an evaporator breach
- The importance of training can not be overestimated when trying to minimize the time personnel spend in an ionizing radiation field.
- CIPAS electrical connector should be redesigned so that it can be plugged in while on the pad

Conclusions

- MMRTG secondary cooling was successfully established and the transition from secondary cooling to primary cooling proceeded smoothly and safely. The Descent Stage pressurant tanks remained well below 30^{o}C at all times
- Installation of the CHRS jumper tubes was completed and the CHRS system was verified to meet leak rate criteria prior to fill and startup
- The CHRS loop operated flawlessly from its inception, and was declared ready for launch.
- Success can be attributed to an excellent staffing plan, motivated teammates, procedures that were well written and thoroughly reviewed, and highly trained and skilled technicians
- MSL Launched Successfully on November 26, 2011 with 2 fully functional HRS loops

Acknowledgements

The development described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors express their thanks to the Mars Science Laboratory rover project sponsored by NASA for supporting this effort. The authors also wish to thank several of their colleagues at JPL who were instrumental to enabling successful HRS launch pad closeout activities: Joe Mora, Larry Harma, John Shuping, Jorge Garcia, Alex Mora, Neil Laugen, Ray Higuera, Saverio D'Agostino, Mark Anderson, Jeff Umland, Paul Lytal, Peter Illsley, Mark Yerdon, Jennifer Knight, Paul Hardy, Ben Thoma, David Gruel, Elizabeth Dewell, John Wirth, Art Thompson, Jordan Evans, Ron Welch, James Colvin, David Woerner, John Beatty, Barry Coleman, Shaun Stott, Sarah Marshall, Greg De Los Santos, Bert Turney, Rick Paynter, Mark Phillips, Marcum Martz, and Eric Sunada. The authors also thank Matt Antoniu, Beau Simmons, and Barry Clarkson who supported the fabrication of the ATS Chillers and Jeffrey Budny who supported the fabrication of the Lockheed Martin SSP and FFC. Lastly, the authors wish to thank the many other individuals outside of JPL who personally assisted the HRS team to overcome some difficult challenges – Eric Robinson (Omnisafe, Inc.), Greg Peralta (KSC), Eric Poole (KSC), John Pavone (KSC), Brian Lawson (KSC), Reed Divertie (KSC), John Hueckel (KSC), Laura Bales (KSC), Joan Wenaas (ULA), Kelly Lively (INL), Carla Dwight (INL), Greg Hula (INL), Shannon Bragg-Sitton (INL), Eric Clarke (INL), Steve Johnson (INL), Robin Stewart (INL), Lucas Rich (INL), Amy Powell (INL), Jamie Mitchell (INL), Chris Browning (INL), Courtney Swassing (INL), Jon Bradley (INL), SueAnn Keller (INL), Jeremy Anderson (INL), Leo Gard (PWR), Bill Otting (PWR), Russell Bennett (Teledyne), and Bill Bohne (DOE/NE-75).



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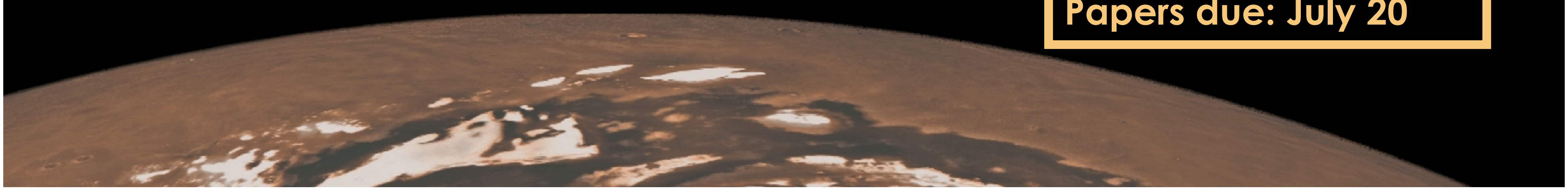


BACKUPS

MSL Project Overview

<u>Salient Features</u>

Mobile Science Laboratory

One Mars Year surface operational lifetime (669 sols/687 days)

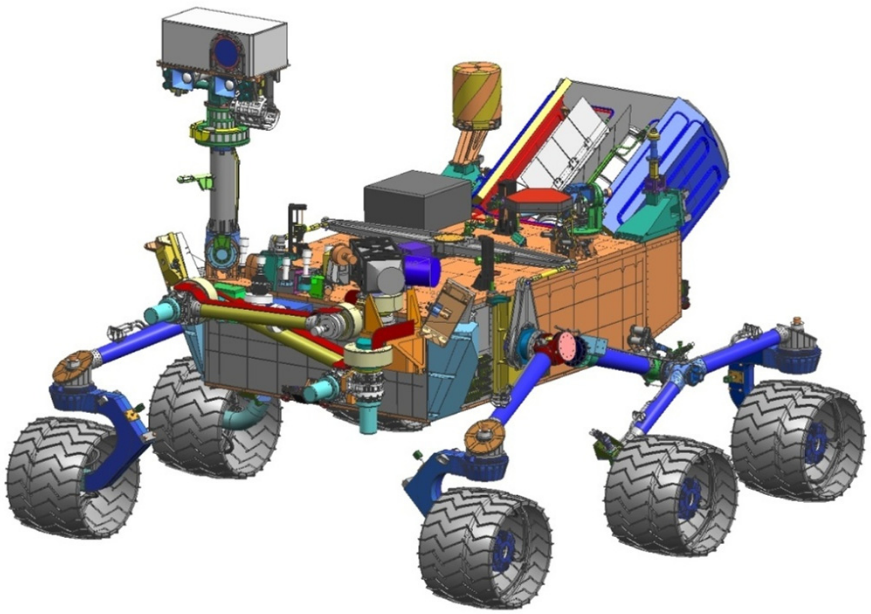
Landing Capability over wide range of latitudes ($\pm$ 30°)

Controlled Propulsive Landing

Precision Landing via Guided Entry

Mass = 950 kg

Launch: Nov 25, 2011; Landing: Aug 5, 2012



<u>Science</u>

Mission science will focus on Mars habitability

Next generation analytical laboratory science investigations (SAM & Chemin)

Remote sensing/contact investigations (MastCam,ChemCam, MAHLI & APXS)

Suite of Environmental Monitoring Instruments (DAN, REMS, MARDI & RAD)

MSL Spacecraft